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SU-SEL-68-048

Measurement of Maximum Time-Delay Resolution of Oblique Soundings on East-West and North-South Paths

by

J. T. Lynch
R. B. Fenwick
O. G. Villard, Jr.

JUNE 1968

TECHNICAL REPORT NO. 146

Prepared under
Office of Naval Research Contract
Nonr-225(64), NR 088 019, and
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RADIOSCIENCE LABORATORY

STANFORD ELECTRONICS LABORATORIES

STANFORD UNIVERSITY · STANFORD, CALIFORNIA

SEL-68-048

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Radioscience Laboratory
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ABSTRACT

The purpose of this investigation was to determine the maximum usable bandwidth of an HF, ionospheric channel, in a system which does not compensate for ionospheric distortion. A high-resolution, oblique "chirp" FM-CW sounder was used to measure the minimum equivalent pulse widths which could be transmitted over paths having characteristics typical, respectively, of geomagnetically east-west and north-south propagation. The path used to represent east-west propagation was from Lubbock, Texas to Stanford, California. The path used to represent north-south propagation was from Bozeman, Montana to Stanford.

It was found that propagation on a one-hop sporadic-E mode offered the best opportunity to transmit pulses with the least distortion, while the one-hop F-layer mode under daytime conditions was next best. The pulse widening measured on the east-west (Lubbock) path is relatively small because this path is approximately perpendicular to the earth's magnetic field. The data indicated that, at the best radio frequency, 3 μsec pulses could be propagated by the 1-F mode during 50 percent of the daylight hours.

The north-south (Bozeman) path is not perpendicular to the earth's magnetic field; thus the pulse splitting caused by o-x propagation is significant on this path. The data indicated that 5 μsec pulses could be propagated during 50 percent of the daylight hours by the 1-F mode at the best frequency.

Changes in the shape of the curve of group delay vs frequency (shown by an "oblique ionogram") can greatly change the amount of pulse dispersion; thus care must be taken in applying the results of the present study to any specific problem. The data from both experiments showed that the best resolution occurred at about 0.7 of the maximum operating frequency (MOF); above 0.9 MOF the dispersion was quite severe.

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I. INTRODUCTION

The purpose of this investigation was to determine the widest bandwidth ionospheric channel which can be effectively used without compensating for ionospheric distortion. A high-resolution FM-CW "chirp" oblique sounder was used to measure the minimum pulse widths which could be transmitted over paths having characteristics typical, respectively, of geomagnetically east-west and north-south propagation.

The path used to represent east-west propagation was from Lubbock, Texas to Stanford, California, a distance of 1880 km. The path used to represent north-south propagation was from Bozeman, Montana to Stanford, a distance of 1300 km. These paths will be referred to hereafter as the "east-west" and the "north-south" paths, respectively.

The oblique sounder used in the experiments transmitted a CW signal whose frequency changed linearly with time and which produced a display of group delay vs frequency--the standard "oblique-ionogram" presentation. The sounding equipment, developed at Stanford University, has the capability of processing signals for an equivalent 3 dB pulse width of less than 2 μsec. Thus, distortion which widens a pulse by more than 2 μsec could be measured in the experiments reported here.

The one-hop F-layer lower-ray mode was analyzed in all of the experiments because it gives the best results consistent with a large amount of data. The E and E_s layers can give very good propagation characteristics; however, such propagation did not occur frequently enough in the present study to be of interest. The index of relative magnetic quiet was low on all of the days during which data were taken, so the data may be considered typical for non-disturbed ionospheric conditions. A sounding was made and recorded every 30 seconds for about 48 hours. Approximately 5,000 records were made for each path. Data taken every half hour were scaled and reduced for inclusion in this report; thus approximately 90 records were analyzed.

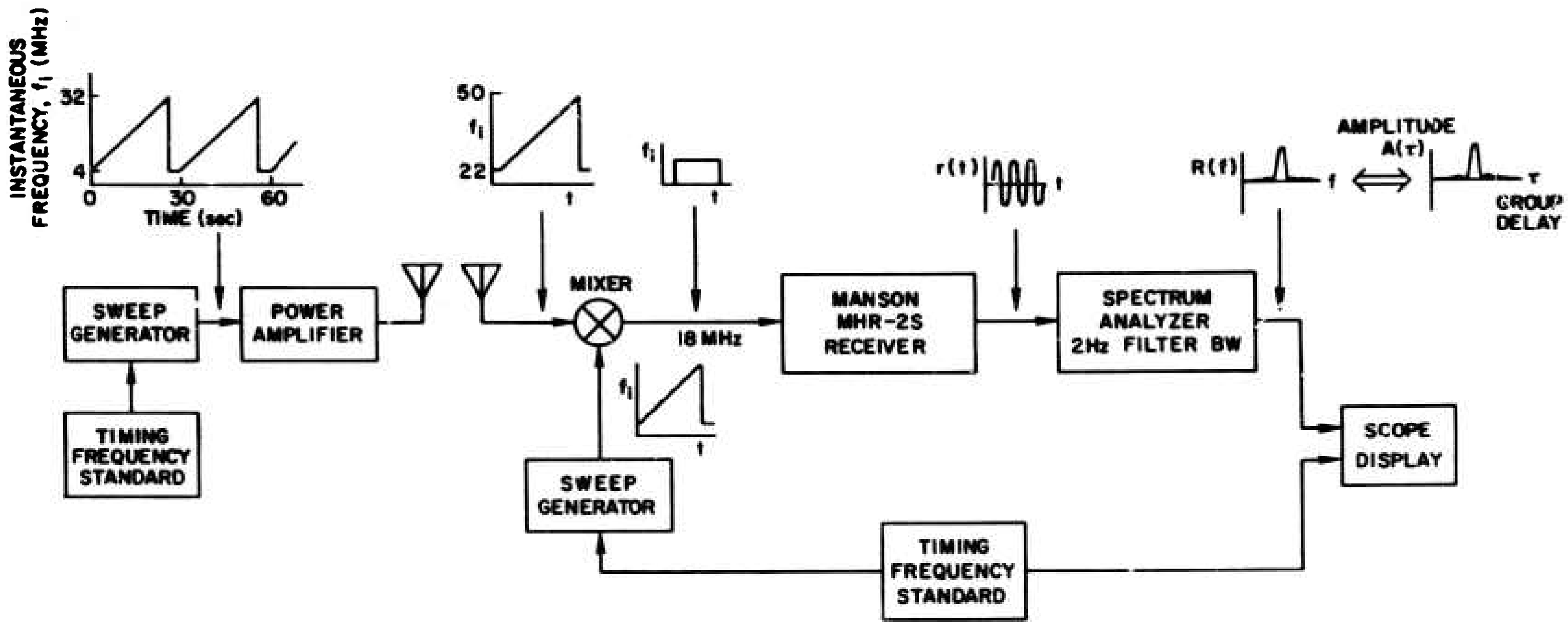


Fig. 1. FM-CW SOUNDER BLOCK DIAGRAM.

II. EQUIPMENT DESCRIPTION

A general description of the equipment used for the east-west path (Lubbock to Stanford) is given below. A more detailed description of the design and operation of the FM-CW sounding equipment may be found in Refs. 1 and 2. The minor equipment differences between the Lubbock-to-Stanford and the Bozeman-to-Stanford experiments are described at the end of this section.

A block diagram of the FM-CW sounding system is shown in Fig. 1. The basic component of the system is a sweep-frequency generator whose instantaneous output frequency is a linear function of time. The frequency sweeps from 4 to 32 MHz at a rate of 1 MHz per second, each 30 sec. The starting time of the sweep and the absolute frequency are controlled by a frequency standard. For the Lubbock experiment a Hewlett-Packard cesium beam time standard was used to synchronize the starting times to within 300 nsec. Such accurate timing is useful for determining absolute range and equivalent path length; however, this capability was not needed for the work reported here. A 100 W distributed amplifier was used to drive a horizontally polarized log-periodic antenna (LPA) (Granger 747L).

The receiving system, which was on the Stanford University campus, consisted of a log-periodic antenna, a broadband mixer, a sweep generator, a frequency standard, a radio receiver, a spectrum analyzer, and an oscilloscope display. The log-periodic antenna, which was horizontally polarized, fed the signal to the broadband mixer. The local oscillator for the mixer was a linear FM signal generated at the receiver. It had characteristics identical to those of the transmitted waveform except for the frequency limits. The 18 MHz, IF signal was amplified and bandlimited by a Manson MHR-2S receiver. The coherent IF #1 output of the receiver was spectrum-analyzed over a 1000 Hz bandwidth with 2 Hz resolution. Because the rate of the sweep generator was 1 MHz per second (1 Hz/μsec), use of a 2 Hz bandwidth in the spectrum analyzer gave a time-delay resolution of 2 μsec. The phase accuracy of the sweep generator was adequate to give better than 200 nsec resolution with side lobes more than 20 dB down.

It should be noted that the term "resolution", which refers to the ability to distinguish in time delay among closely-spaced returns, has many formal definitions. The simplest of these is used in this report: namely, the width of the processed "equivalent pulse" measured at a point 3 dB (.707) down from the peak.

The spectrum analyzer used had a built-in resolution bandwidth of 40 Hz; therefore, it was necessary to record the data (with an analog recorder) and play it back at 20 times the recording speed in order to achieve the desired 2 Hz resolution. The distortion introduced by the tape recorder that was used was small, and did not degrade the system resolution or introduce spurious signals to an extent which would affect the results presented here.

The data were displayed by means of a photograph of a sequence of oscilloscope "A-display" traces. This technique permitted the amplitude, the group delay, and the propagating frequency to be displayed on the scope without using z-axis (intensity) modulation. The dynamic range attained in this way (approximately 20 dB) permitted detailed scaling of the record.

If the input to the spectrum analyzer is a single-tone sinusoidal signal, the output is an amplitude-vs-frequency "pulse" whose amplitude is a measure of the amplitude of the input signal, whose position is a measure of the frequency of the input signal, and whose shape is the response of the spectrum-analyzer filter. The spectrum analyzer is triggered to generate an output pulse every half second, thus allowing changes in the input to be observed. The sequence of output pulses is photographed by a camera which advances film continuously past the lens at a very slow rate (say 1/4 inch per second).

If the spectrum analyzer input is a pure-tone CW signal, the film record would appear as in Fig. 2a. If the frequency of the input signal is slowly changing, the film record might appear as in Fig. 2b. Because the input frequency of the spectrum analyzer is a measure of the group delay of the oblique path, and because the transmitted frequency changes linearly with time, the data recorded on the film represent group delay vs transmitted frequency--and therefore form part of an "oblique ionogram." An example of such a display for the one-hop lower-F-ray mode is shown

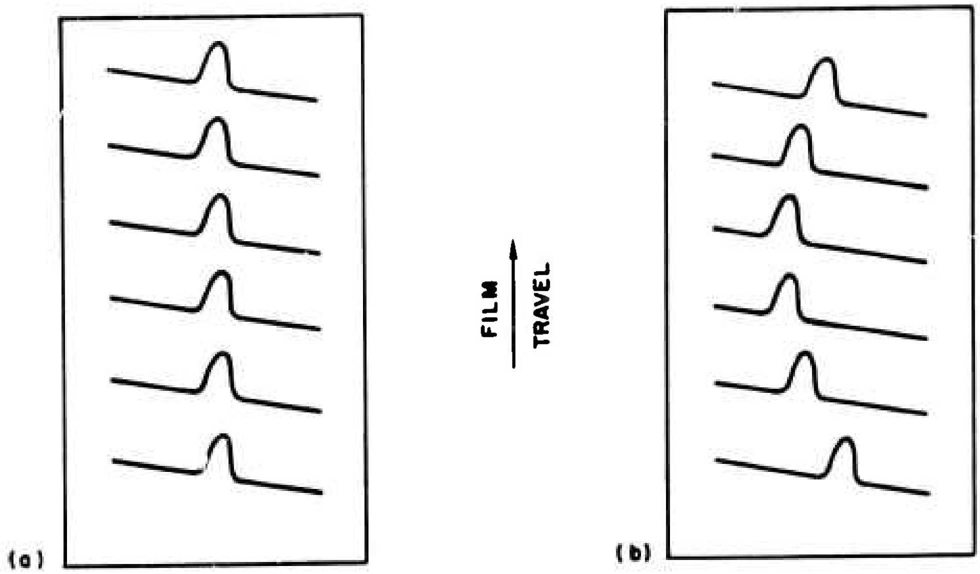
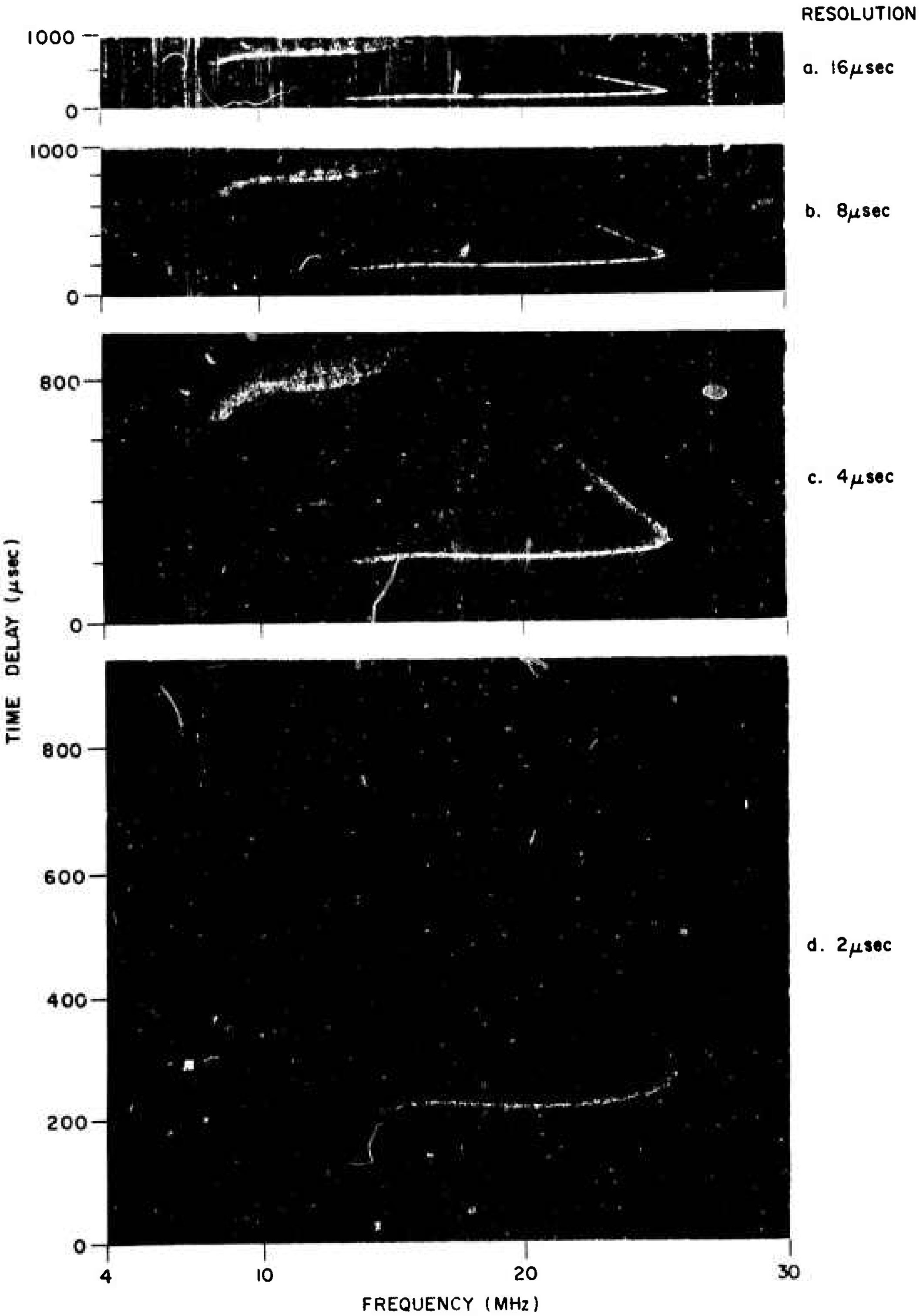


Fig. 2. FILM DISPLAY OF SPECTRUM ANALYZER OUTPUT.
a. Constant input-signal frequency
b. Slowly changing input-signal frequency

in Fig. 3. Figures 3a, b, c, d, and e show the same ionogram displayed with increasing degrees of resolution.

The equipment used for the north-south experiment with transmitter at Bozeman was similar to that just described, except for minor differences. A crystal oscillator was used for the frequency standard, and the receiving antenna at Stanford was a cross-polarized log-periodic antenna which permitted the recording of approximations to vertical, horizontal, left-circular, and right-circular polarization. In addition, the signal from the horizontally polarized antenna was fed directly to the processing equipment. The spectrum analyzer (made by Federal Scientific Corporation, Model UA-7) permitted greater flexibility in selecting the resolution bandwidth. Thus, it was not necessary to play back tape-recorded data at a rapid speed to achieve the desired resolution. The additional flexibility permitted the use of a 1 Hz bandwidth, thus giving the system a 1 μsec time-delay resolution.



RESOLUTION
a. 16μsec
b. 8μsec
c. 4μsec
d. 2μsec
TIME DELAY (μsec)
1000
0
1000
0
800
0
800
600
400
200
0
4
10
20
30
FREQUENCY (MHz)

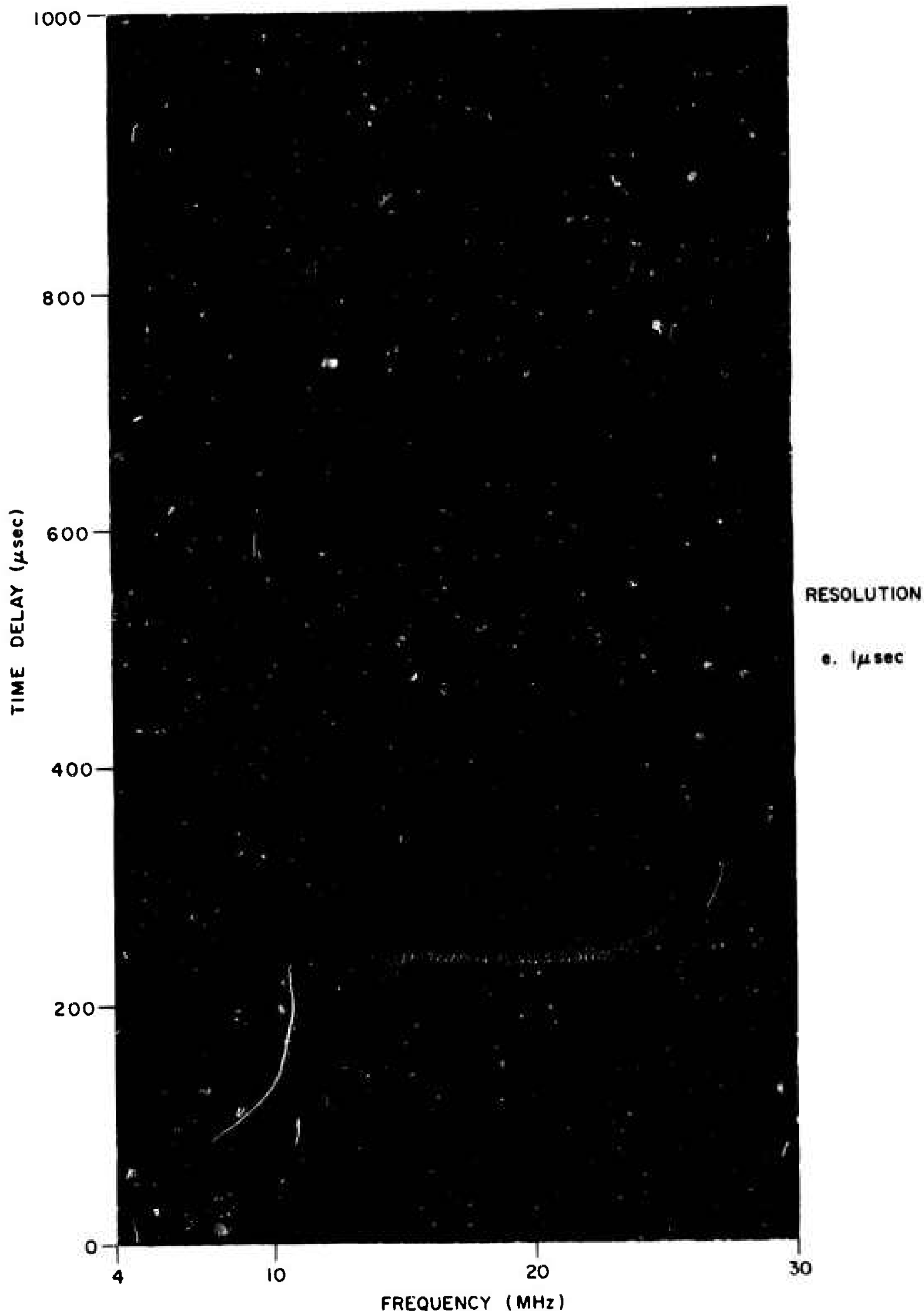


Fig. 3. TYPICAL DAYTIME IONOGRAMS FOR LUBBOCK-STANFORD (EAST-WEST) PATH: 17 DECEMBER 1966, 1752 GMT.

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III. EXPERIMENTAL RESULTS

The paths used in the experiments are shown on the map, Fig. 4. From the map it is seen that the direction of the Lubbock-Stanford path is almost east to west. The direction of the Bozeman-Stanford path is approximately northeast to southwest. However, this path has propagation characteristics typical of a north-south path, because it deviates by a large angle from the normal to the earth's magnetic field. For this reason, it is referred to herein as the "north-south" path.

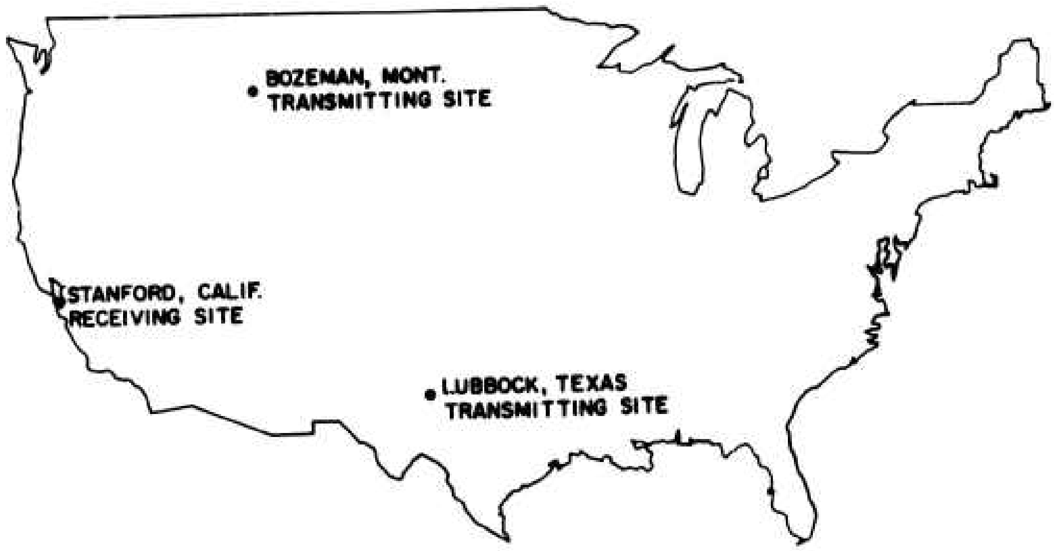
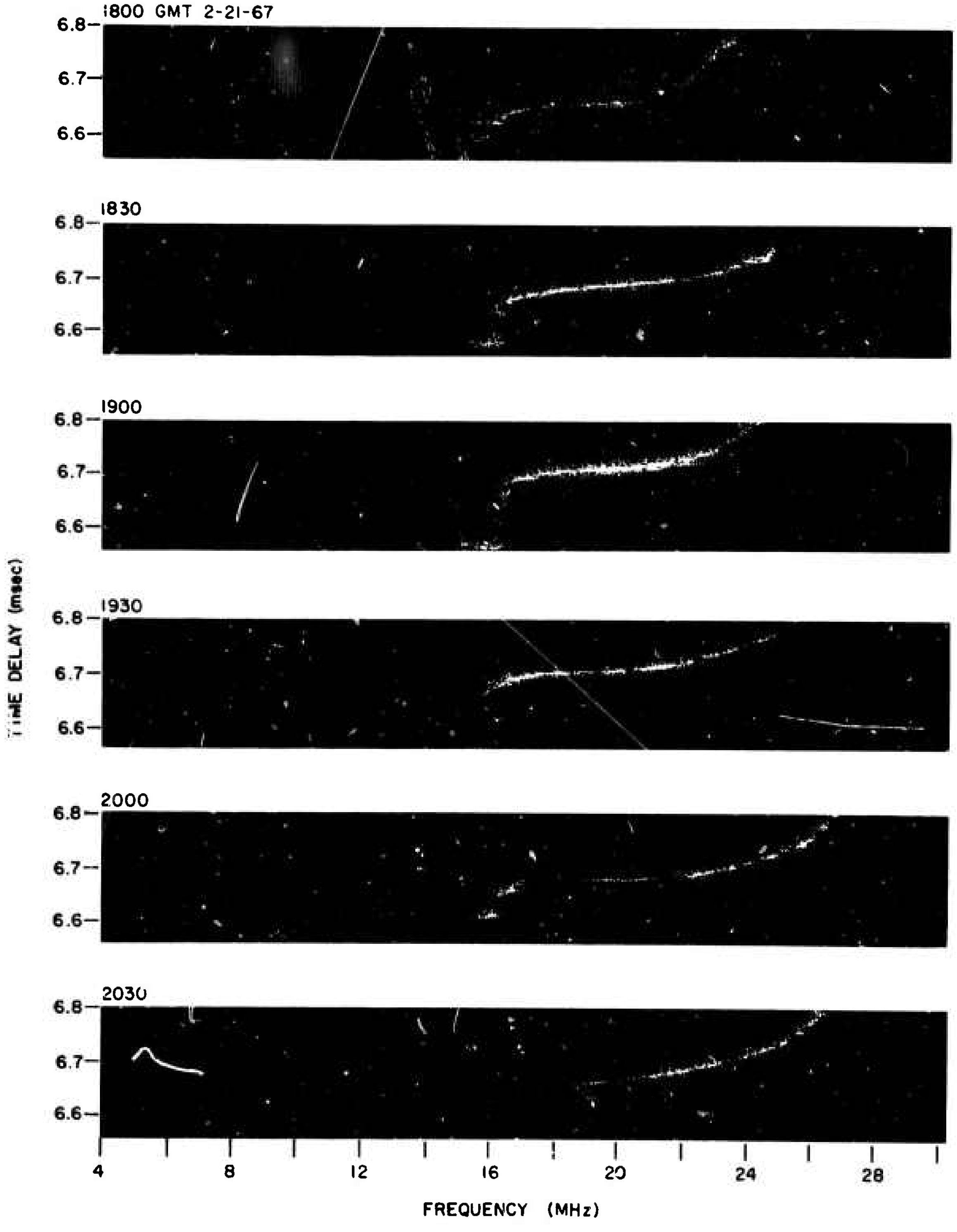


Fig. 4. MAP OF PATHS.

A. DAYTIME RECORDS: LUBBOCK (EAST-WEST PATH)

Figures 5 and 6 show soundings made on the Lubbock-Stanford path at half-hour intervals for six daylight hours on two consecutive days (21 and 22 February, 1967). The soundings show the one-hop F-layer lower-ray propagation mode with a 6.55-6.80 msec time-delay window (corresponding to 225-350 km virtual reflection height). Note that because this east-west, one-hop path is moderately long and is approximately perpendicular to the earth's magnetic field, the pulse splitting caused by o and x propagation is slight, and is not apparent on the records. Also observe that for frequency bands where the group delay is a constant $\left(\frac{d\tau_g}{df} \cong 0\right)$--i.e., when there is small dispersion--the pulse width is approximately



1800 GMT 2-21-67
1830
1900
1930
2000
2030
6.8
6.7
6.6
TIME DELAY (msec)
4
8
12
16
20
24
28
FREQUENCY (MHz)

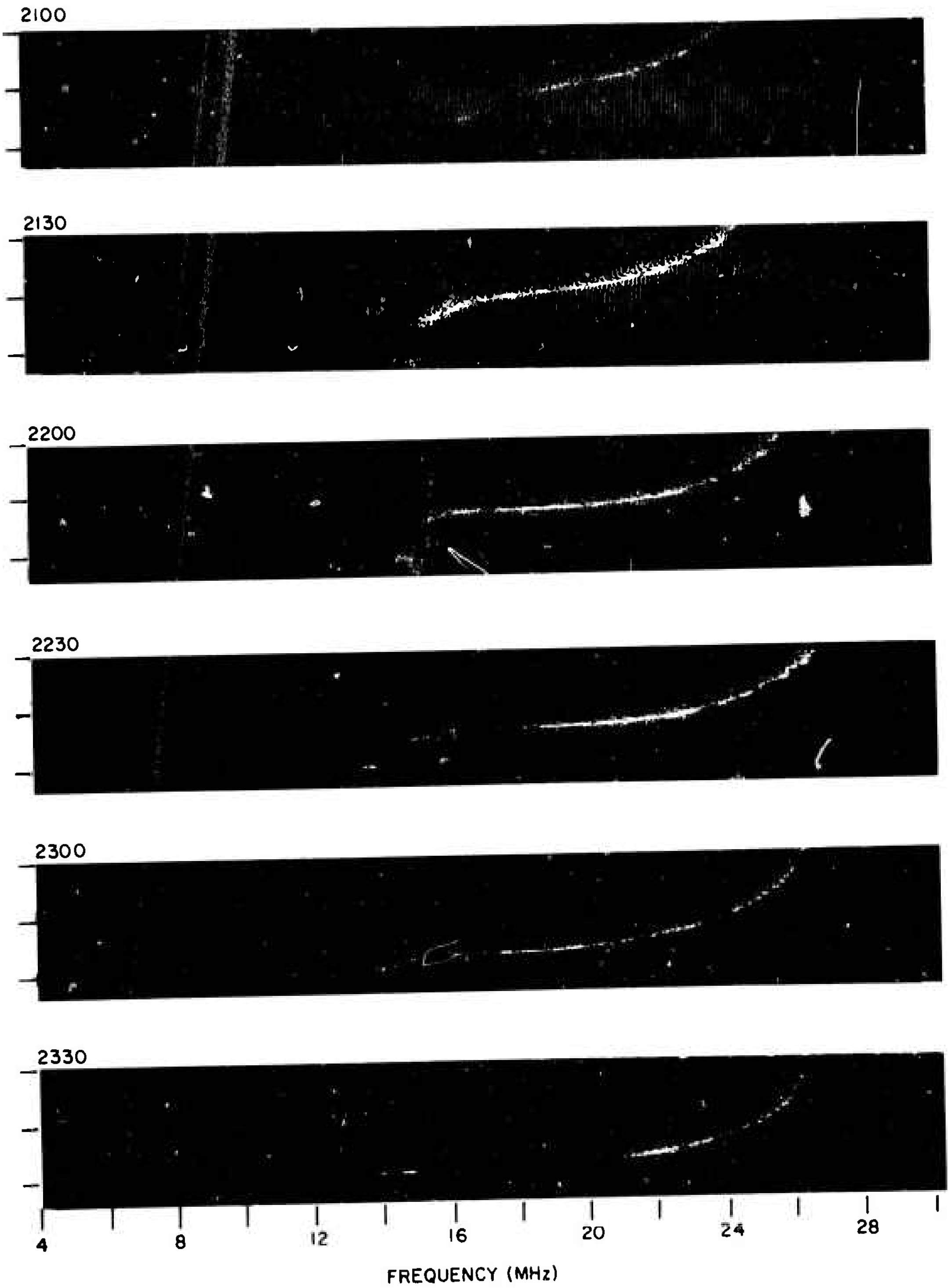
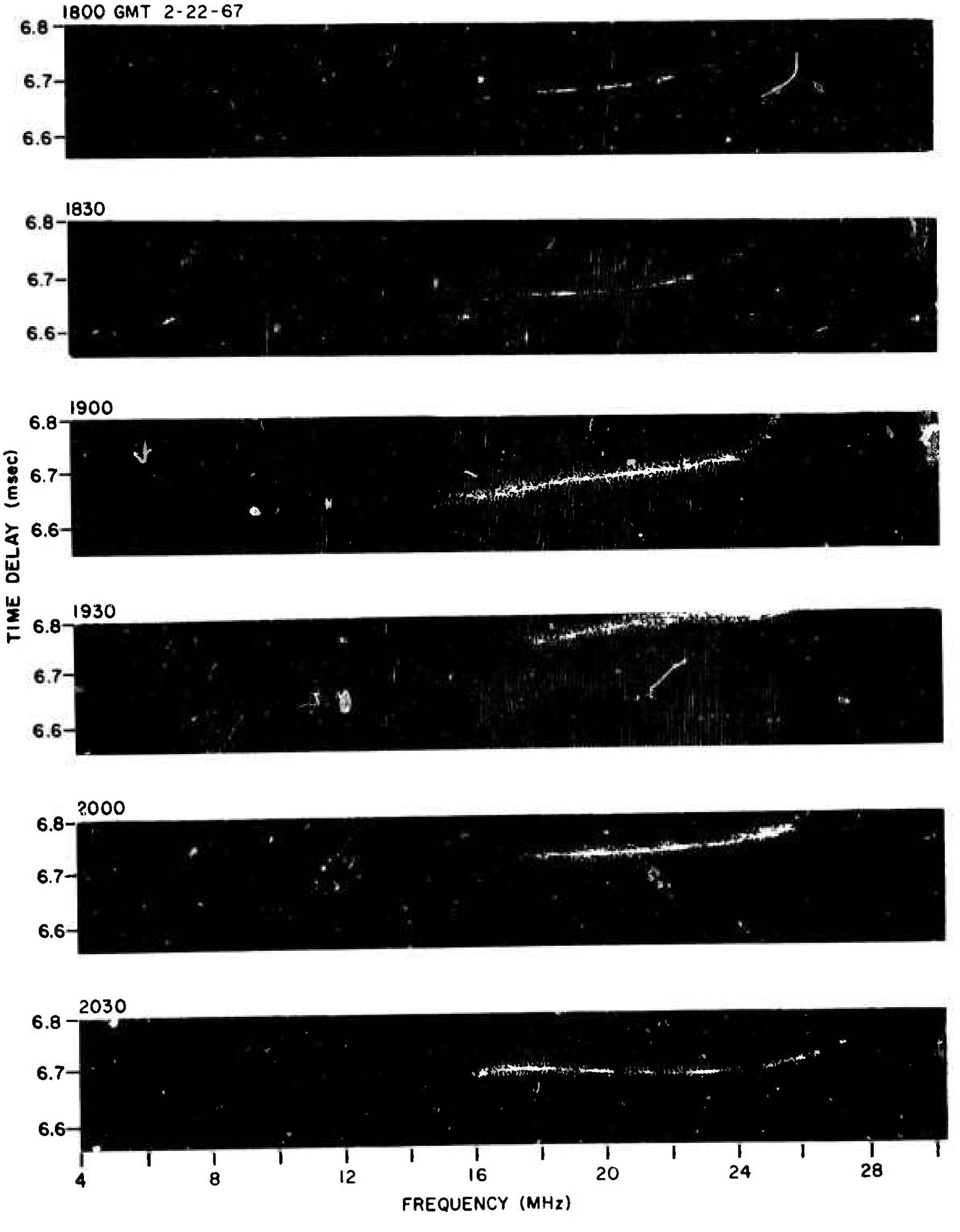


Fig. 5. DAYLIGHT SOUNDINGS AT HALF-HOUR INTERVALS OVER LUBBOCK-STANFORD (EAST-WEST) PATH: 21 FEBRUARY 1967.


1800 GMT 2-22-67
1830
1900
1930
2000
2030
6.8
6.7
6.6
TIME DELAY (msec)
4
8
12
16
20
24
28
FREQUENCY (MHz)

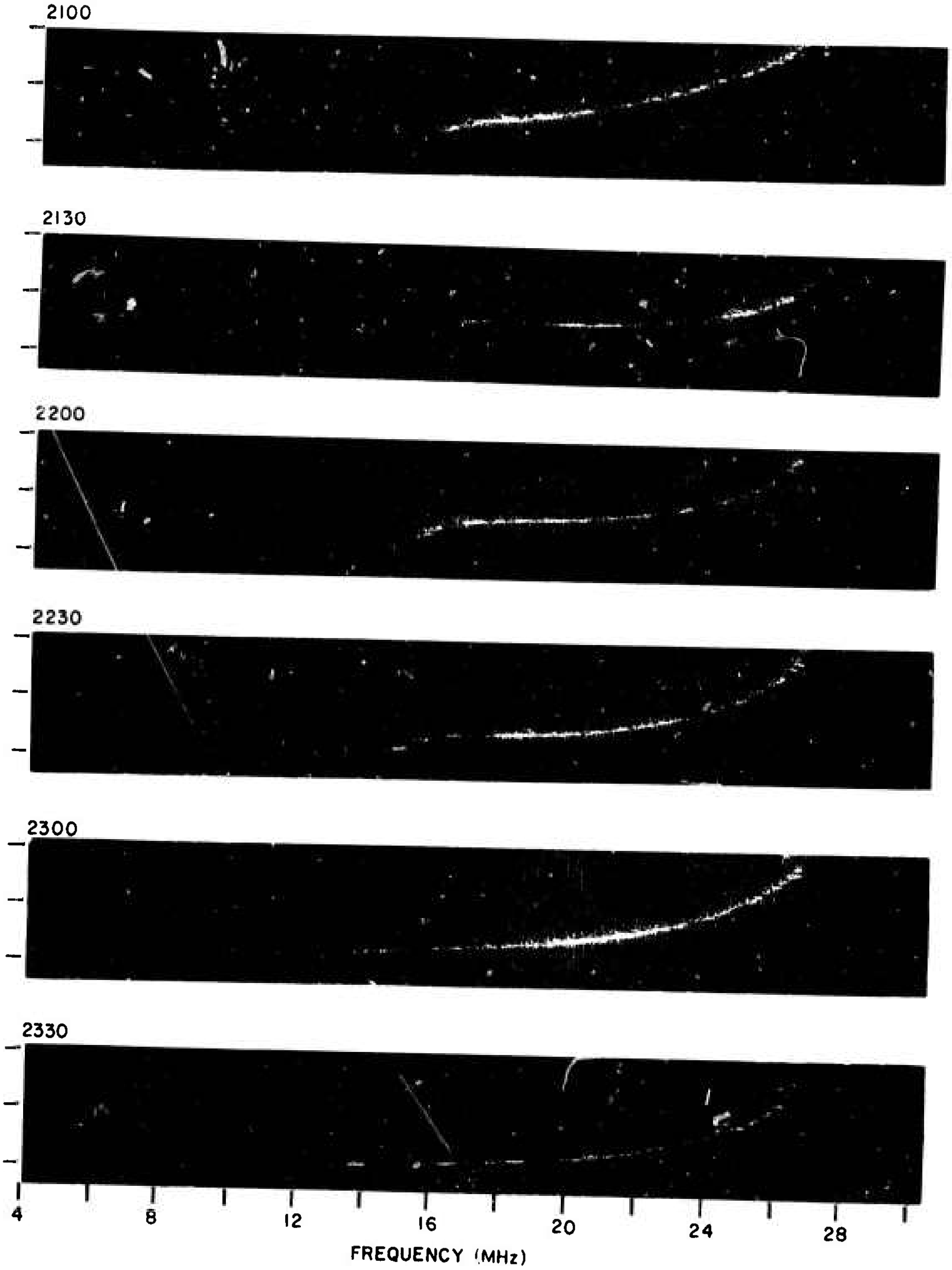


Fig. 6. DAYLIGHT SOUNDINGS AT HALF-HOUR INTERVALS OVER LUBBOCK-STANFORD (EAST-WEST) PATH: 22 FEBRUARY 1967.

2 μsec (see the record for 20:00 GMT, Fig. 5). For the dispersive part of the curve the pulse widths are as large as 30 μsec.

B. DAYTIME RECORDS: BOZEMAN (NORTH-SOUTH PATH)

Three typical soundings of the one-hop F-layer lower-ray mode are shown in Fig. 7a for the Bozeman-Stanford path. These data were recorded for a 48-hour period starting 17 October 1967 and ending 19 October 1967. The time-delay window shown in 500 μsec wide. (The absolute delay cannot be specified.) Because, as pointed out above, the Bozeman-Stanford path is shorter than the Lubbock-Stanford path and is not perpendicular to the earth's magnetic field, there is observed considerable pulse splitting caused by o-x propagation. At certain frequencies the separation of the pulses is approximately 2 to 3 μsec, as shown in Fig. 7b, which is an enlargement of a portion of Fig. 7a.

C. DATA ANALYSIS

Figure 8 indicates the narrowest observed 3 dB pulse widths (resolution) for the Lubbock path as a function of time of day. One record was scaled for each half hour of the day for 2 days. From this graph it is seen that during daylight hours, 3 μsec resolution was achieved at <u>some</u> frequency about 50 percent of the time, and 2 μsec resolution was achieved about 25 percent of the time. Figure 9 gives the maximum observed frequency (MOF), the lowest observed frequency (LOF), and the frequency range for which 2 μsec resolution was achieved. Note that because the curve of group delay vs frequency is flat over a large portion of the ionogram (see Fig. 6), the narrow pulse widths are achieved for a relatively wide band of frequencies. The frequency at which the best resolution occurs, expressed as a percentage of the MOF, is shown in Fig. 10. This graph indicates that for these data, on the average, the best resolution occurs at about 72 percent of the MOF. (MOF here was measured as the lower-ray-upper-ray junction frequency.)

Measurements from the Bozeman data are shown in Figs. 11, 12 and 13, which correspond to the Lubbock data presented in Figs. 8, 9, and 10. Figure 11 gives the best resolution vs time of day; from this graph it is seen that during the daylight hours, 5 μsec resolution was achieved

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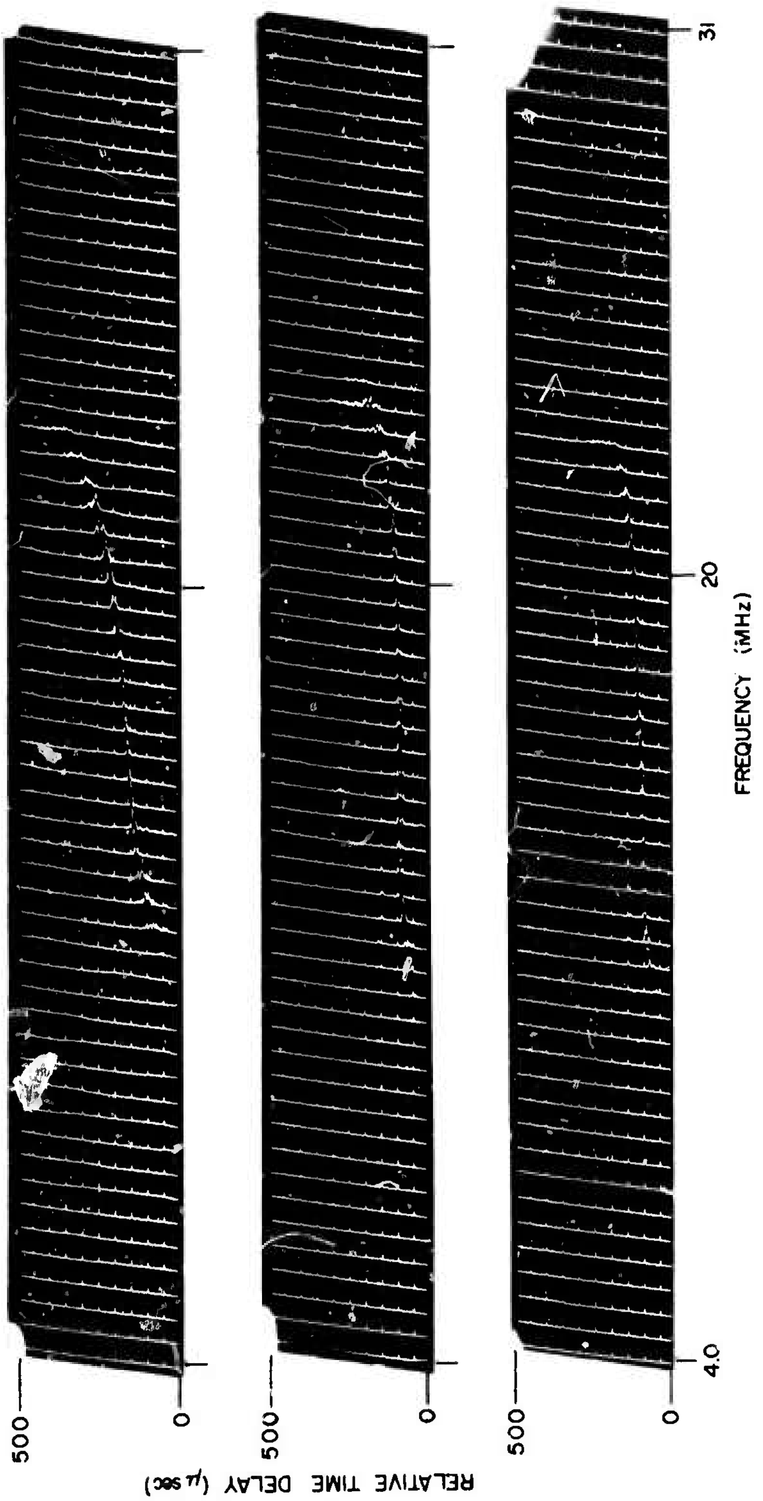
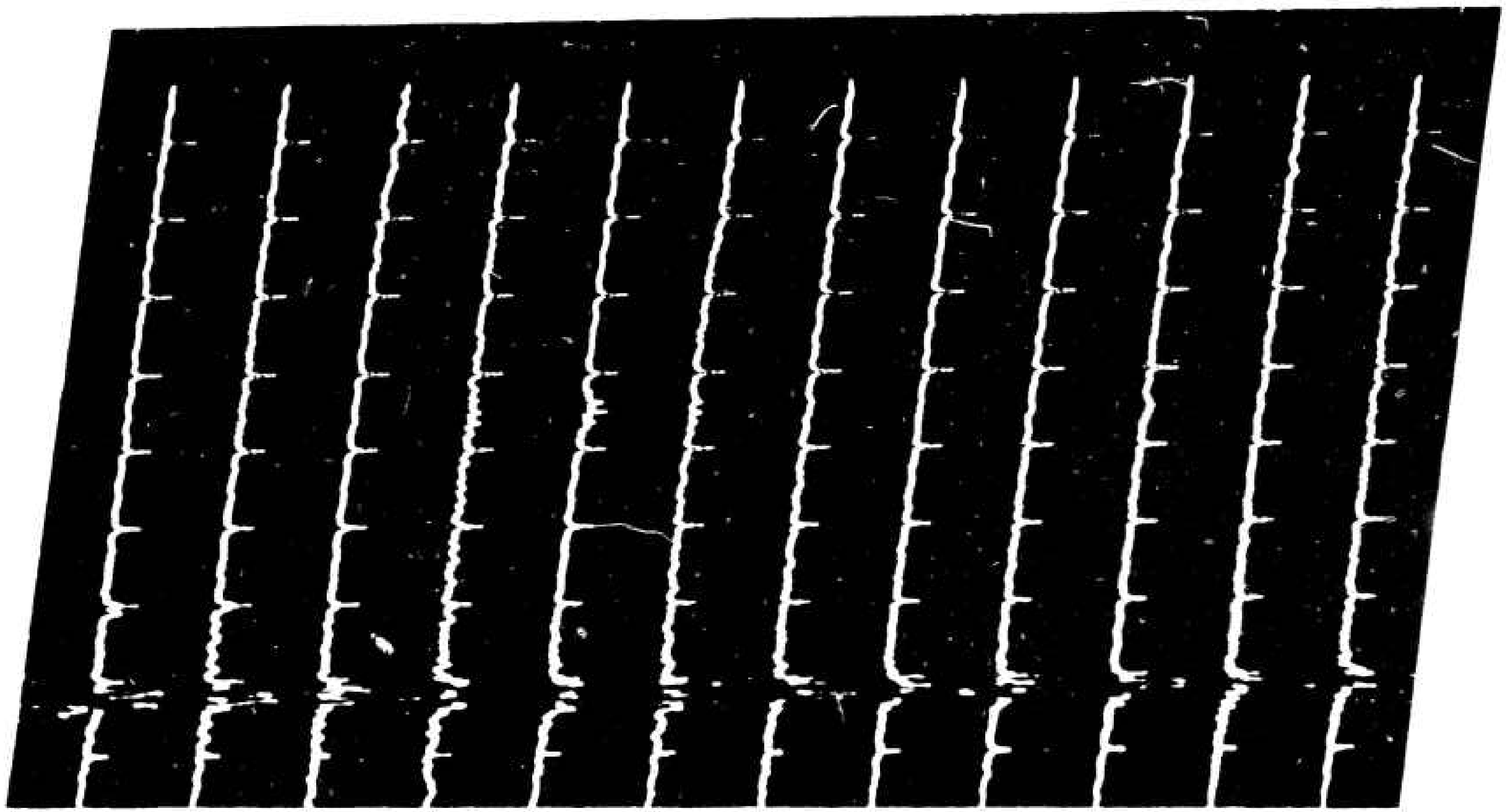


a. As recorded.



b. Enlargement of a portion of (a).

Fig. 7. TYPICAL DAYLIGHT SOUNDINGS OVER BOZEMAN-STANFORD (NORTH-SOUTH) PATH, OCTOBER 1967.

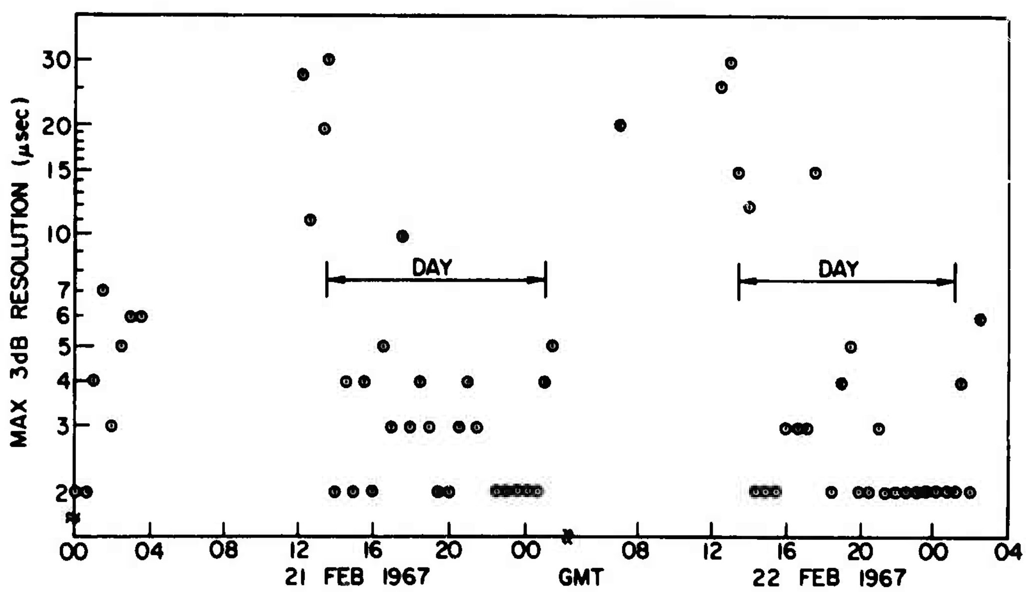


Fig. 8. MAXIMUM 3 dB RESOLUTION VS. GMT, LUBBOCK PATH.

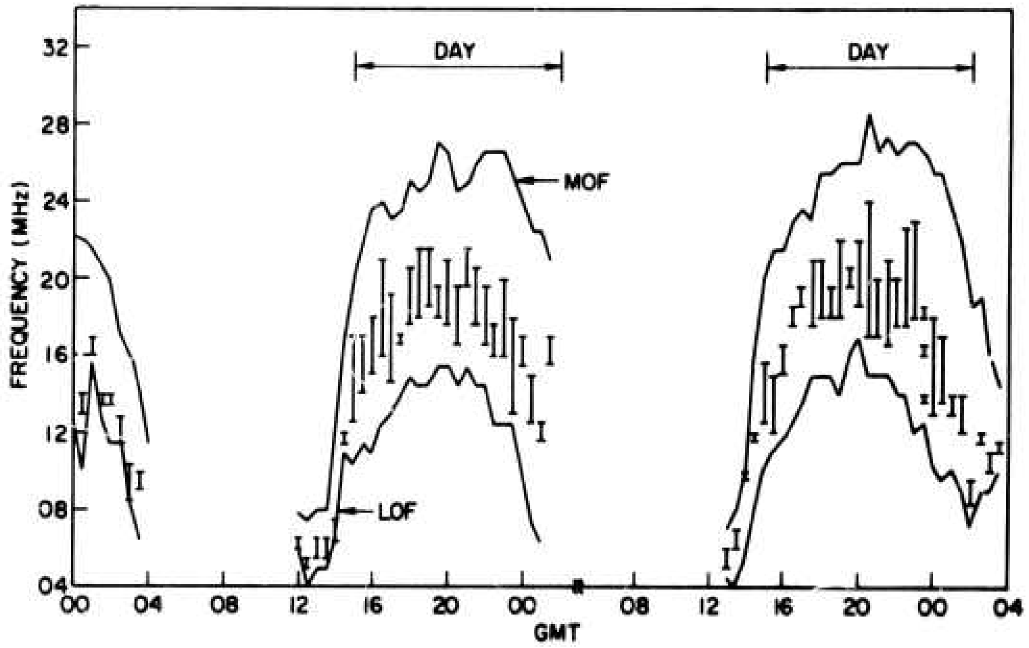


Fig. 9. HIGH-RESOLUTION FREQUENCY BANDS (BETTER THAN 2 μsec), LUBBOCK PATH. (1-hop F-layer).

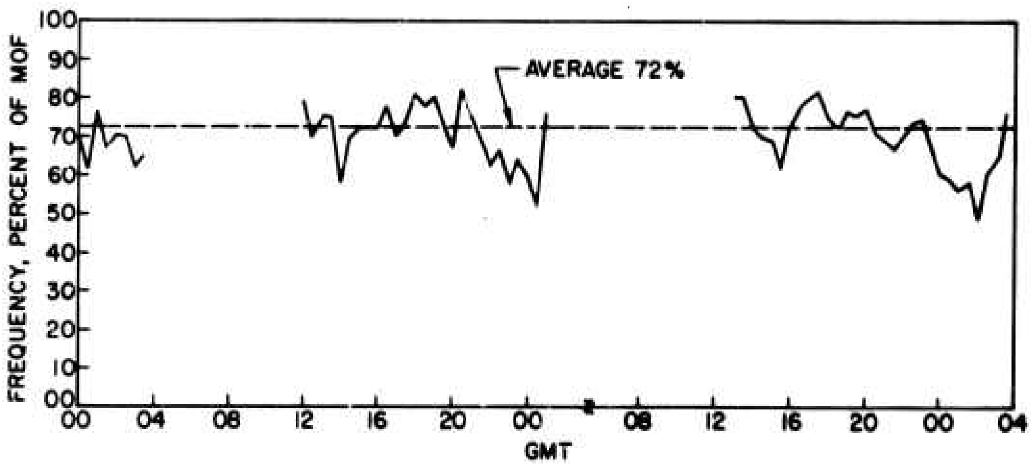


Fig. 10. FREQUENCY GIVING MAXIMUM RESOLUTION, EXPRESSED AS A PERCENT OF MOF. LUBBOCK PATH.

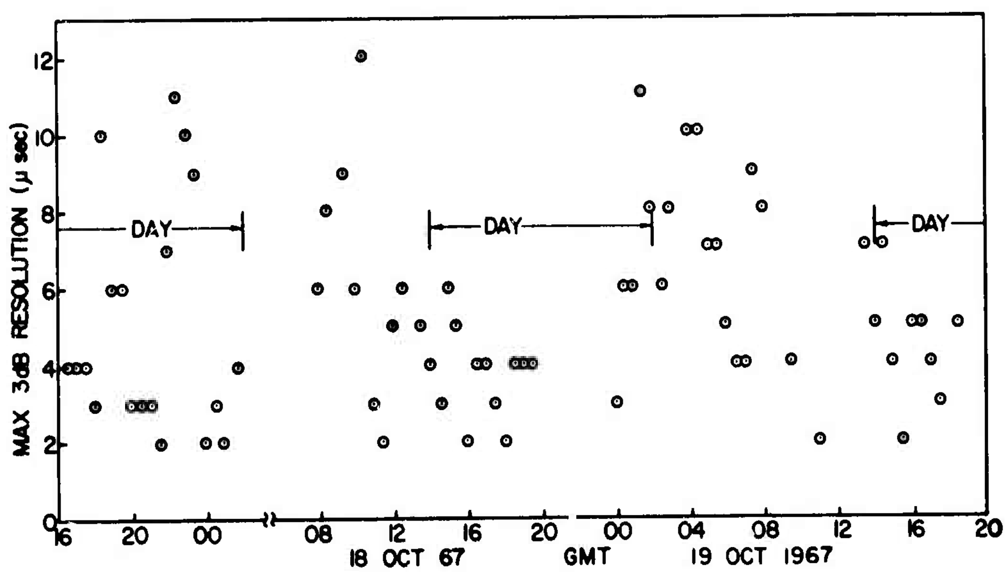


Fig. 11. MAXIMUM 3 dB RESOLUTION VS. GMT, BOZEMAN PATH.

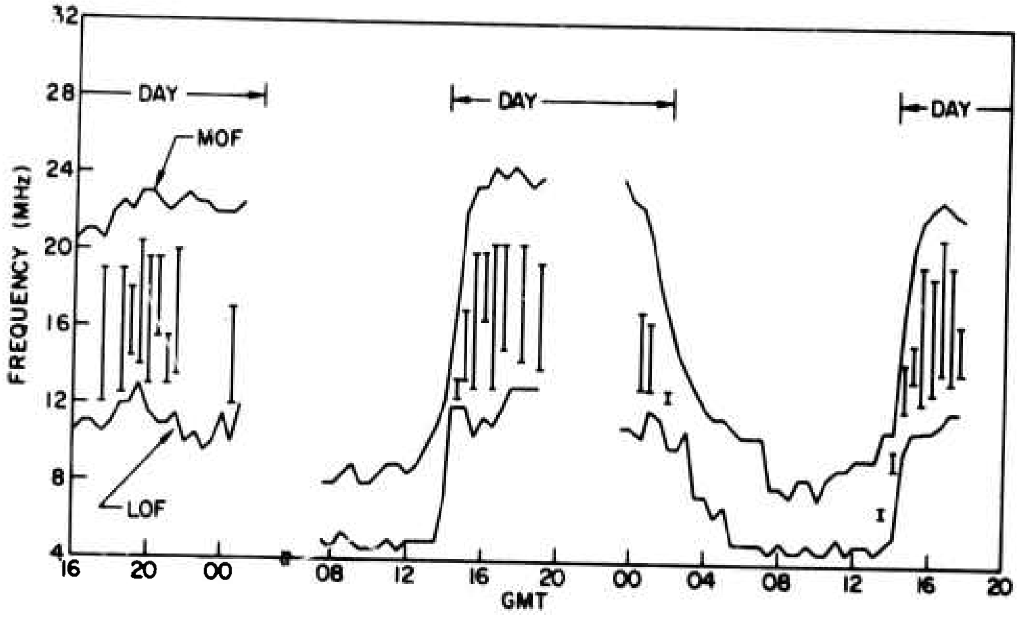


Fig. 12. HIGH RESOLUTION FREQUENCY BANDS (BETTER THAN 5 μsec), BOZEMAN PATH.
(1-hop F-layer).

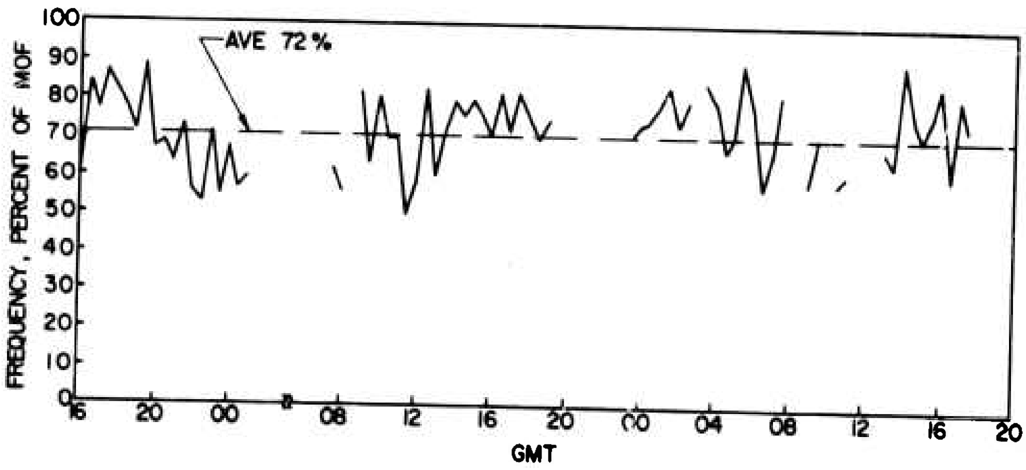


Fig. 13. FREQUENCY GIVING MAXIMUM RESOLUTION, EXPRESSED AS A PERCENT OF MOF. BOZEMAN PATH.

50 percent of the time. The poorer resolution on the Bozeman path, as compared with the Lubbock path, is attributable in part to the greater o-x time-delay splitting on the Bozeman path and in part to the fact that the Bozeman path is shorter.

Figure 12 gives the MOF, LOF, and range of frequencies for which the measured minimum pulse width was less than 5 μsec, and Fig. 13 gives the frequency at which the best resolution occurred, expressed as a percentage of the MOF. The average percentage frequency for the data plotted in Fig. 13 was calculated to be 72 percent, which is coincidentally the same as the value measured for the Lubbock path.

The curve of group delay vs frequency for the Bozeman path is not as flat as the curve for the Lubbock path; thus wide frequency bands of good resolution should not be expected. Furthermore, the difference in the group time delay for the ""o" and "x" rays changes as a function of frequency. To illustrate the effect of this changing difference in group delay, an idealized F-layer ionogram is sketched in Fig. 14 The differences in the o-x curves are emphasized in order to point out that as the curves cross, the combined pulsewidth will be a minimum at the frequency of crossing. This illustrates qualitatively why good resolution did not occur for wide bandwidths in the case of the Bozeman path, where o-x time delay differentials are greater. A more complete explanation of this effect may be found in Ref. 3. The effect also suggests a rationale for explaining why the best resolution occurred at a constant percentage of the MOF (in this case 72 percent). To prove this hypothesis, however, would require a much more extensive data-taking exercise, beyond the scope of the present experiment.

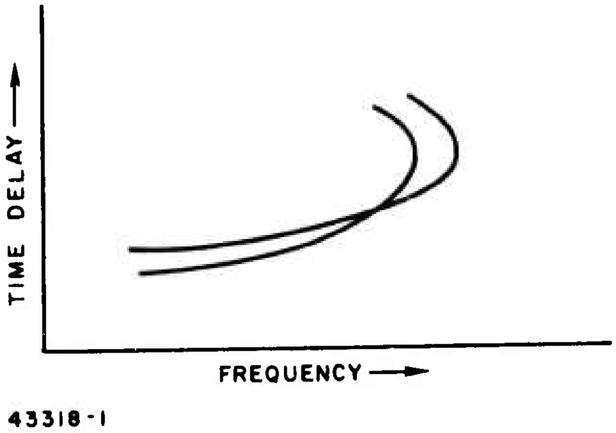


Fig. 14. IDEALIZED SKETCH OF A TYPICAL F-LAYER IONOGRAM, EMPHASIZING o-x SPLITTING.

IV. CONCLUSIONS

Propagation on a one-hop, F-layer lower-ray mode during daytime conditions offers the best routine opportunity to transmit short pulses having the least distortion. (E-region modes can be better, however.) The pulse widening measured on the east-west (Lubbock) path was observed to be relatively small because of the path length and the fact that the path is approximately perpendicular to the earth's magnetic field. The data indicated that 3 μsec pulses could be propagated with negligible broadening during 50 percent of the daylight hours.

The north-south (Bozeman) path is shorter than the east-west path and is not perpendicular to the earth's magnetic field; thus the pulse splitting caused by o-x propagation is more significant on this path. The data indicated that 5 μsec pulses could be propagated during 50 percent of the daylight hours.

It should be noted, however, that changes in the shape of the curve of group delay vs frequency can greatly change the amount of pulse dispersion; thus care must be taken in applying the results of the present study to any specific problem. The data from both experiments did indicate, however, that the best resolution occurred at about 0.7 MOF (junction frequency) and that above 0.9 MOF the dispersion was quite severe.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
HF SOUNDING						
HF RADIO						
RADAR						
IONOSPHERIC PROPAGATION						

ABSTRACT (Cont)

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